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US Army Research Laboratory

Ballistic Evaluation of 2060 Aluminum

by Denver B Gallardy

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by Denver B Gallardy
Weapons and Materials Research Directorate, ARL

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14. ABSTRACT
The US Army Research Laboratory evaluated the ballistic performance of aluminum alloy (AA) 2060-T8 produced by Alcoa as part of a Defense Acquisition Challenge Program. Ballistic evaluation was performed using armor-piercing and fragment-simulating projectiles to determine the V_{50} ballistic-protection limit (V_{50}) for various thicknesses of material. The V_{50} was then compared with other ballistic-grade AAs, namely AA2195 and AA2139. The results of these experiments were used to derive the acceptance tables for AA2060 included in the updated military specification MIL-DTL-32341A (MR).

15. SUBJECT TERMS
aluminum, armor, V_{50}, 2060, 6055, Defense Acquisition Challenge, ballistic acceptance

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Contents

List of Figures

List of Tables

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1. Introduction

In 2012 a Defense Acquisition Challenge (DAC) program proposal was submitted to the US Office of the Secretary of Defense (OSD) to provide improved armor-plate materials for production and repair of existing or new aluminum (Al)-based monocoque armored-vehicle hulls such as those of the M2 Bradley Infantry Fighting Vehicles. Also in 2012 the Aluminum Association assigned a new 2XXX-series alloy designation to Alcoa for aluminum alloy (AA) 2060, granting it full commercial availability as rolled plate from Davenport, IA. AA2060 remains under patent protection and is solely manufactured by Alcoa. AA2060 was confirmed as having similar mechanical properties as the AA2195 alloy and therefore became the basis for a fiscal year 2012 OSD-funded DAC program to fully validate and ultimately transition AA2060 for availability as an appliqué armor plate in US acquisition. The ballistics goal of this program was to verify that AA2060-T8 met or exceeded the performance of AA2195-T64.[1]

Several thicknesses of 2060-T8 were provided to ARL by Alcoa. Table 1 is a summary matrix of the tested thicknesses subjected to impacts from various munitions including armor-piercing (AP) and fragment-simulating projectiles (FSPs). Additionally, Table 2 provides the required chemistries for AA2060 as well as other common Al-armor alloys.

Table 1 Test matrix for AA2060 indicating the number of plates tested

Nominal plate gage (mm)	0.30-cal. APM2 30° obliquity	0.30-cal. APM2 0° obliquity	0.50-cal. APM2 0° obliquity	0.50-cal. FSP 0° obliquity	20-mm FSP 0° obliquity
12.70	2	…	…	…	…
19.05	1	1	…	1	…
25.40	…	3	…	3	3
31.75	…	1	…	…	1
38.10	…	4	4	…	4
50.80	…	…	3	…	2
57.15	…	…	1	…	…
63.50	…	…	2	…	…

Table 2 Chemistry of AAs' weight-percent ranges[2]

Element	2139	2195	2519	5083	6061	2060	7039	7085
Copper	4.5–5.5	3.70–4.30	5.30–6.40	0.10 max	0.15–0.40	3.40–4.50	0.10 max	1.3–2.0
Iron	0.15 max	0.15 max	0.30 max[a]	0.40 max	0.70 max	0.07 max	0.40 max	0.08 max
Lithium	…	0.80–1.20	…	…	…	0.60–0.90	…	…
Chromium	0.05 max	…	…	0.05–0.25	0.04–0.35	…	0.15–0.25	0.04 max
Manganese	0.20–0.60	0.25 max	0.10–0.50	0.40–1.0	0.15 max	0.10–0.50	0.10–0.40	0.04 max
Magnesium	0.20–0.80	0.25–0.80	0.05–0.40	4.0–4.90	0.8–1.2	0.60–1.10	2.30–3.30	1.2–1.8
Silicon	0.10 max	0.12 max	0.25 max[a]	0.40 max	0.40 –0.80	0.07 max	0.30 max	0.06 max
Titanium	0.15 max	0.10 max	0.02–0.10	0.15 max	0.15 max	0.10 max	0.10 max	0.06 max
Zinc	0.25 max	0.25 max	0.10 max	0.25 max	0.25 max	0.30–0.50	3.50–4.50	7.0–8.0
Zirconium	…	0.08–0.16	0.10–0.25	…	…	0.05–0.15	…	0.08–0.15
Silver	0.15–0.60	0.25–0.60	…	…	…	0.05–0.50	…	…
Others (each)	0.05 max	0.05 max	0.05 max	0.05 max	0.05 max	0.05 max	0.05 max	0.05 max
Others (total)	0.15 max	0.15 max	0.15 max	0.15 max	0.15 max	0.15 max	0.15 max	0.15 max
Aluminum	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder

[a]The total weight percentage of the combination of silicon and iron cannot exceed 0.40%.

2. Experimental Procedure

The V_{50} is defined as the impact velocity at which the projectile is equally as likely to penetrate the target as it is to arrest. A 0.51-mm (0.020-inch) 2024 T3 Al witness plate was positioned 152 mm (6 inches) behind the target to determine the outcome of each shot. An impact is regarded as a complete penetration (CP), or loss, if the projectile or a resulting target fragment from impact creates a hole in the witness plate through which light can be observed. If an impact does not result in a CP, it is considered a partial penetration (PP), or win. To keep results as consistent as possible, only shots conforming to the following conditions were used to determine the V_{50}: The projectile must be unyawed—less than 2° of total yaw for AP rounds and less than 5° of total yaw for FSPs—and strike the target at least 2 projectile diameters from any previous impact or damage or the edge of the target. Total yaw is defined as the vector sum of the projectile's pitch and yaw. The V_{50} is calculated by the arithmetic mean of an equal number of CPs and PPs within an 18-m/s (60-ft/s) spread for a 2 + 2 V_{50}, a 27-m/s (90-ft/s) spread for a 3 + 3 V_{50}, and as small of a spread as attainable for a 5 + 5 V_{50}.[3]

Projectile velocities for the determination of the V_{50} were measured using one of 2 methods, as shown in Fig. 1. The first method is an orthogonal flash X-ray system, described in detail by Grabarek and Herr,[4] which also measures pitch and yaw. The second method uses 3 infrared (IR) screens and a chronograph. The velocity is calculated using the first and third screens with the middle screen used to check for

bad readings. The flash X-ray method was used in situations with projectiles that historically exhibit excessive yaw or if space did not allow for the use of the IR break screens. When the IR break screens and chronograph were used, the projectile velocity was corrected to the target-impact location using a correction factor based on an initial flash X-ray reading at the impact location. The correction was made using Eqs. 1 and 2 in lieu of using the following air-drag factors:

$$\frac{(\text{x-ray velocity})}{(\text{chronograph velocity})} = (\text{correction factor}). \quad (1)$$

$$(\text{correction factor}) \times (\text{chronograph velocity}) = (\text{corrected velocity}). \quad (2)$$

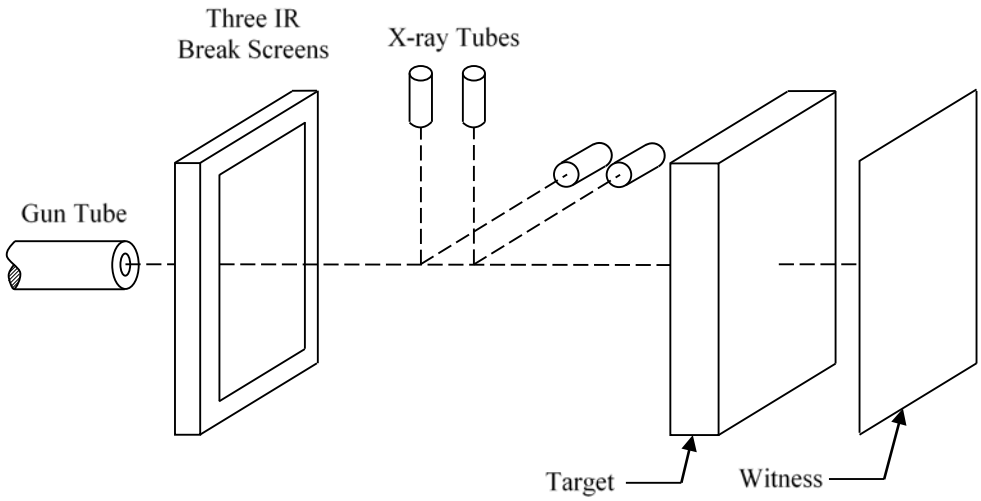

Fig. 1 Typical test setup

3. Test Projectiles

3.1 Armor-Piercing Projectiles

The US 0.30-cal. and 0.50-cal. APM2 are the 2 AP projectiles that were used in this study. These projectiles are shown in Fig. 2. The APM2 projectiles have hardened steel cores with a Rockwell hardness of C61–65. The physical characteristics of these projectiles are listed in Table 3.

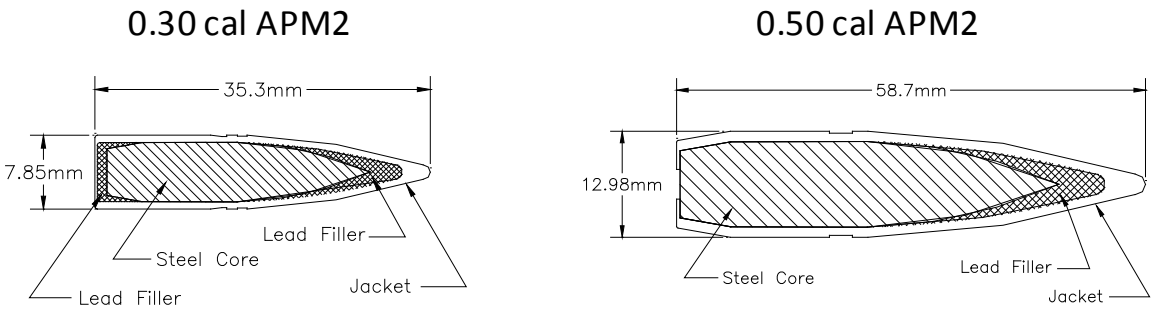

Fig. 2 AP projectiles

Table 3 AP projectiles' physical characteristics[5]

Projectile type	Projectile			Core		
	Length (mm)	Diameter (mm)	Weight (g)	Length (mm)	Diameter (mm)	Weight (g)
0.30-cal. APM2	35.3	7.85	10.8	27.4	6.2	5.3
0.50-cal. APM2	58.7	12.98	45.9	47.5	10.9	25.9

3.2 Fragment-Simulating Projectiles

FSPs (Fig. 3) are a family of projectiles that are flat-nosed right circular cylinders manufactured to MIL-DTL-46593B (MR).[6] These projectiles are used in material evaluations and acceptance testing to simulate performance against fragments produced from improvised explosive devices and artillery. Both 0.50-cal. and 20-mm FSPs were used for the evaluation of AA2060.

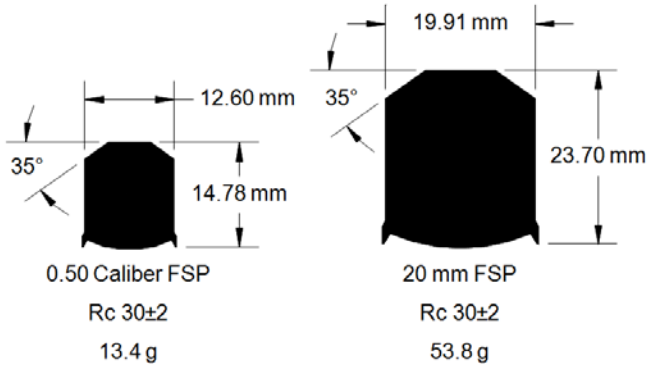

Fig. 3 FSP projectiles

4. Results and Analysis

The test results are summarized in Tables 4–8. The individual shot records are provided in Appendix A, and ballistic data obtained by the US Army Aberdeen Test Center (ATC)[7] are included in Appendix B.

Table 4 APM2 0.30-cal., 30° obliquity V_{50} ballistic limits for AA2060

Plate ID	Nominal thickness		Actual thickness		Areal density		V_{50}		Standard deviation	
	(mm)	(inches)	(mm)	(inches)	(kg/m^2)	(lb/ft^2)	(m/s)	(ft/s)	(m/s)	(ft/s)
215-014	12.70	0.50	15.98	0.629	43.33	8.88	586	1,921	6	19
215-016	12.70	0.50	17.22	0.678	46.71	9.57	628	2,059	6	19
425-801	19.05	0.75	21.62	0.851	58.63	12.01	707	2,319	4	14

Table 5 APM2 0.30-cal., 0° obliquity V_{50} ballistic limits for AA2060

Plate ID	Nominal thickness		Actual thickness		Areal density		V_{50}		Standard deviation	
	(mm)	(inches)	(mm)	(inches)	(kg/m2)	(lb/ft^2)	(m/s)	(ft/s)	(m/s)	(ft/s)
425-801	19.05	0.75	21.62	0.851	58.63	12.01	642	2,107	7	22
215-019	25.40	1.00	22.89	0.901	62.07	12.71	659	2,161	9	30
425-871	25.40	1.00	22.81	0.898	61.86	12.67	667	2,189	8	26
425-841	25.40	1.00	24.38	0.960	66.14	13.55	684	2,243	9	29
425-811	31.75	1.25	30.18	1.188	81.84	16.76	779	2,556	11	36
425-822	38.10	1.50	36.93	1.454	100.17	20.52	889	2,916	6	19
425-852	38.10	1.50	36.60	1.441	99.27	20.33	879	2,884	9	28
215-012	38.10	1.50	38.10	1.500	103.34	21.17	898	2,945	8	26
215-006	38.10	1.50	38.56	1.518	104.58	21.42	906	2,972	7	24

Table 6 APM2 0.50-cal., 0° obliquity V_{50} ballistic limits for AA2060

Plate ID	Nominal thickness		Actual thickness		Areal density		V_{50}		Standard deviation	
	(mm)	(inches)	(mm)	(inches)	(kg/m^2)	(lb/ft^2)	(m/s)	(ft/s)	(m/s)	(ft/s)
425-822	38.10	1.50	36.93	1.454	100.17	20.52	650	2,132	10	32
425-852	38.10	1.50	36.60	1.441	99.27	20.33	648	2,127	5	17
215-012	38.10	1.50	38.10	1.500	103.34	21.17	652	2,140	5	18
215-006	38.10	1.50	38.56	1.518	104.58	21.42	660	2,164	9	28
425-821	50.80	2.00	49.66	1.955	134.68	27.59	772	2,532	6	21
425-851	50.80	2.00	49.50	1.949	134.27	27.50	765	2,509	7	24
425-881	50.80	2.00	49.68	1.956	134.75	27.60	767	2,517	10	32
215-011	57.15	2.25	54.99	2.165	149.15	30.55	806	2,646	6	19
425-831	63.50	2.50	62.08	2.444	168.37	34.48	873	2,864	4	13
425-861	63.50	2.50	61.75	2.431	167.47	34.30	868	2,847	11	36

Table 7 FSP 0.50-cal., 0° obliquity V_{50} ballistic limits for AA2060

Plate ID	Nominal thickness		Actual thickness		Areal density		V_{50}		Standard deviation	
	(mm)	(inches)	(mm)	(inches)	(kg/m^2)	(lb/ft^2)	(m/s)	(ft/s)	(m/s)	(ft/s)
425-801	19.05	0.75	21.62	0.851	58.63	12.01	766	2,514	7	23
215-019	25.40	1.00	22.89	0.901	62.07	12.71	914	2,998	6	19
425-871	25.40	1.00	22.81	0.898	61.86	12.67	903	2,962	6	21
425-841	25.40	1.00	24.38	0.960	66.14	13.55	987	3,239	11	35

Table 8 FSP 20-mm, 0° obliquity V_{50} ballistic limits for AA2060

Plate ID	Nominal thickness		Actual thickness		Areal density		V_{50}		Standard deviation	
	(mm)	(inches)	(mm)	(inches)	(kg/m^2)	(lb/ft^2)	(m/s)	(ft/s)	(m/s)	(ft/s)
215-019	25.40	1.00	22.94	0.903	62.21	12.74	427	1,401	17	56
425-871	25.40	1.00	22.96	0.904	62.28	12.76	396	1,298	5	16
425-841	25.40	1.00	24.21	0.953	65.65	13.45	447	1,468	5	17
425-811	31.75	1.25	30.05	1.183	81.50	16.69	599	1,965	6	19
425-822	38.10	1.50	37.03	1.458	100.44	20.57	881	2,892	8	25
425-852	38.10	1.50	36.60	1.441	99.27	20.33	865	2,839	5	17
215-012	38.10	1.50	38.10	1.500	103.34	21.17	909	2,983	7	22
215-006	38.10	1.50	38.43	1.513	104.23	21.35	923	3,027	1	3
425-821	50.80	2.00	49.53	1.950	134.34	27.51	1213	3,979	6	21
425-851	50.80	2.00	49.53	1.950	134.34	27.51	1233	4,047	8	25

The results of the ballistic evaluation are compared directly against the acceptance curves of AA2195 and AA2139 in MIL-DTL-32341A.[1] Figures 4–8 show the AA2060 test data collected by ARL and ATC as compared with the other specification. The data displayed are the V_{50} as a function of the plate thickness. To allow for a fair comparison against the existing specification, a line depicting the $V_{50} - 2\sigma$ was plotted against the acceptance spec. This line represents a V_{02} rather than a V_{50}. To ensure successful protection at a given thickness, the lower band of the 2σ distribution (V_{02} line) is used to define minimum acceptable performance. A V_{50} falling below this line is considered unacceptable. For comparison purposes it should also be noted that the plates are compared on a thickness basis to be consistent with the specifications; however, the densities of the alloys vary slightly. Both AA2060 and AA2195 have a density of 2.71 g/cm^3 whereas AA2139 has a density of 2.80 g/cm^3.

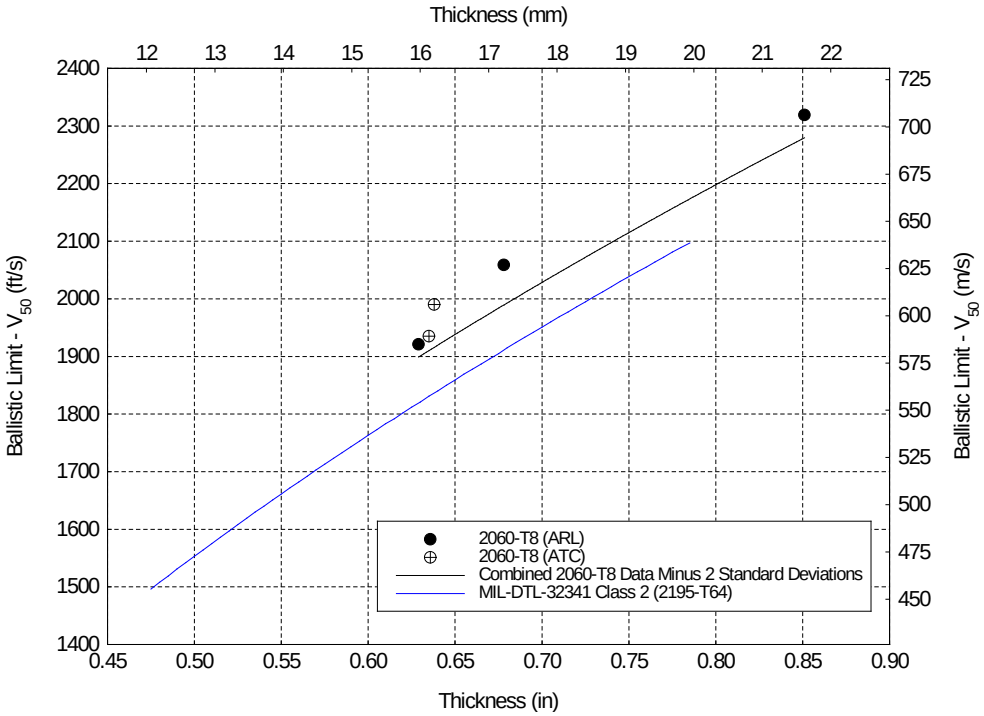

Fig. 4 Ballistic limit vs. thickness of AA2060 as compared with the existing specification for the 0.30-cal. APM2 at 30° obliquity

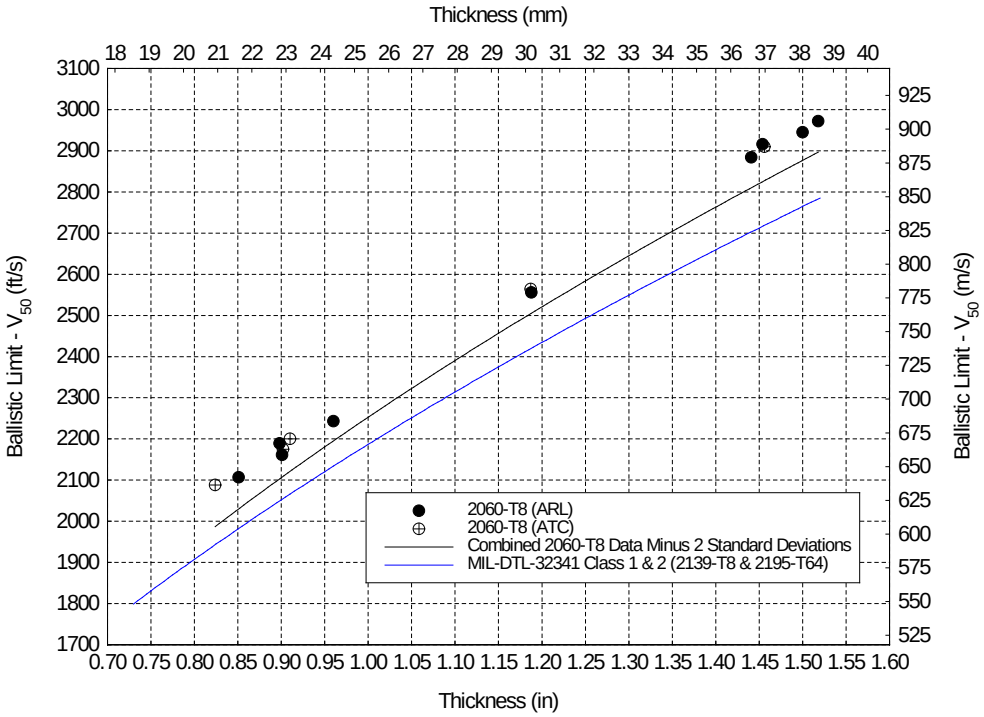

Fig. 5 Ballistic limit vs. thickness of AA2060 as compared with the existing specification for the 0.30-cal. APM2 at 0° obliquity

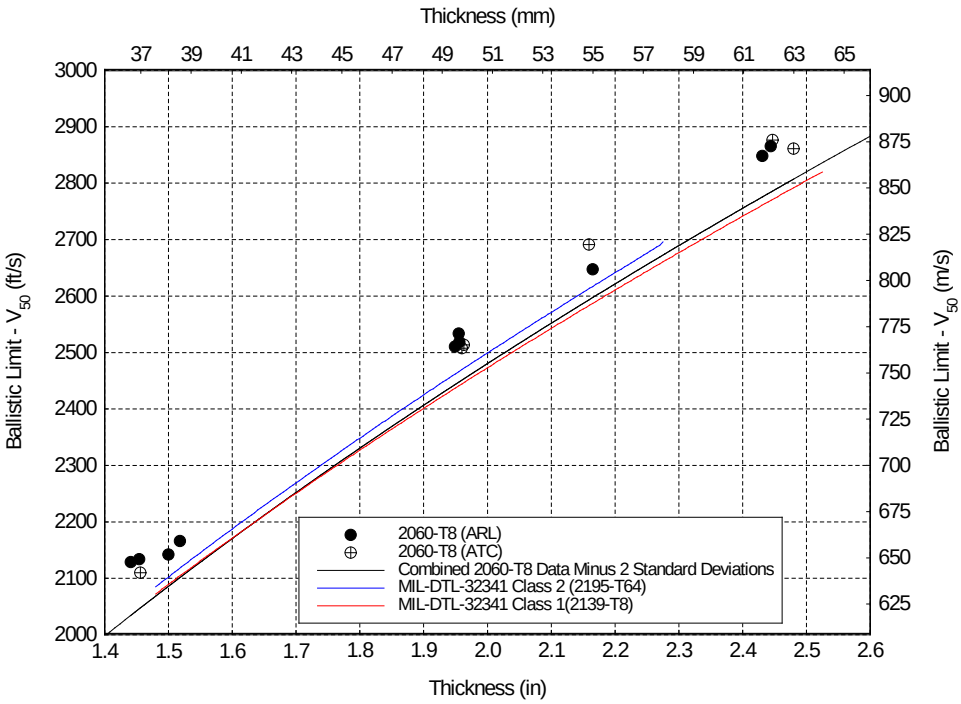

Fig. 6 Ballistic limit vs. thickness of AA2060 as compared with the existing specification for the 0.50-cal. APM2 at 0° obliquity

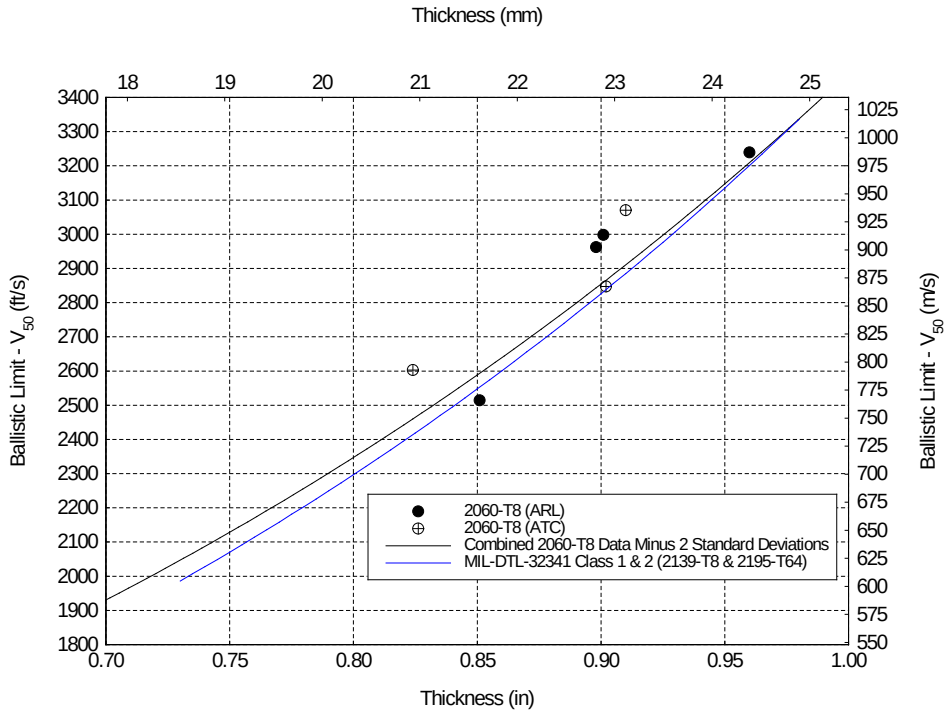

Fig. 7 Ballistic limit vs. thickness of AA2060 as compared with the existing specification for the 0.50-cal. FSP at 0° obliquity

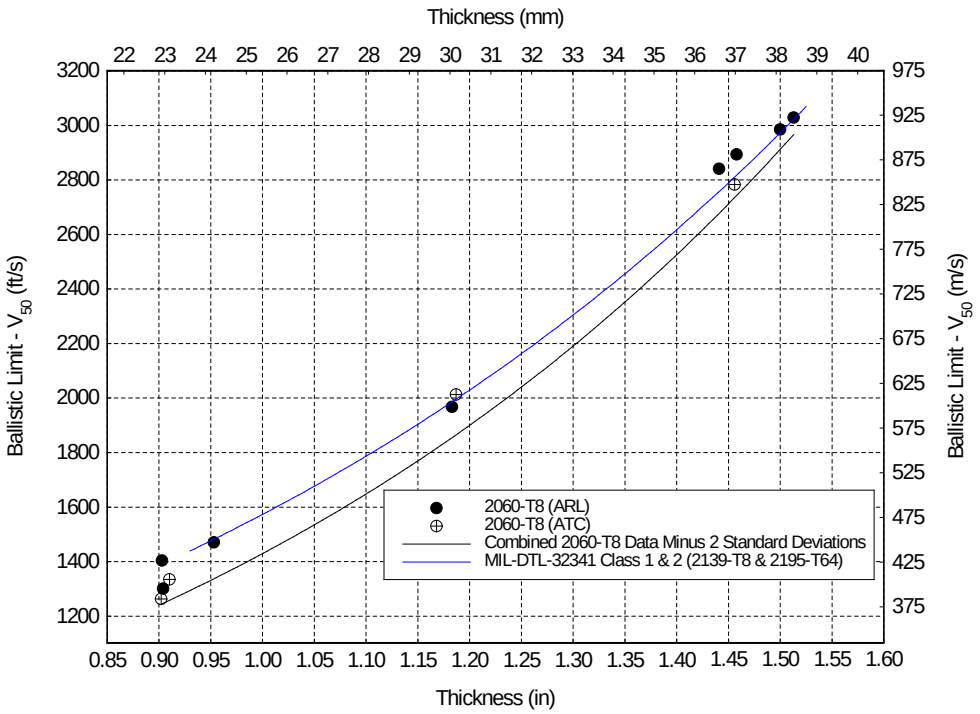

Fig. 8 Ballistic limit vs. thickness of AA2060 as compared with the existing specification for the 20-mm FSP at 0° obliquity

As can be observed in Figs. 4–6, the AP performance for AA2060 is higher than the existing AA2195 and AA2139 acceptance requirements against 0.30-cal. APM2. For the 0.50-cal. APM2, the performance is slightly higher than AA2139 and slightly lower than AA2195. Also note that the maximum thickness evaluated and qualified for AA2060 is 2.5 inches as compared with 2.25 inches for AA2195.

Examining the FSP performance (Figs. 7 and 8), it can be observed that the performance of AA2060 is not as well behaved as the AP data. The 0.50-cal. FSP performance yielded a V_{50} -2σ that was slightly higher than the existing specification but contained 2 data points that fell below that line. For the 20-mm FSP, AA2060 exhibited lower performance than AA2195 and AA2139. The performance gap is greater at lower thickness than higher ones.

The data collected by ARL, as well as data collected by ATC,[7] were then used to generate acceptance tables for MIL-DTL-32341A (MR).[1] The acceptance velocities were calculated by fitting the V_{50} data minus 2 standard deviations with Eqs. 3 and 4 for AP and FSP projectiles, respectively.[8,9]

$$V_A = 1000\sqrt{a+bt}\,. \tag{3}$$

$$V_A = 1000e^{a+bt}\,. \tag{4}$$

In Eqs. 3 and 4, V_A is the acceptance velocity, t is the actual thickness of the plate, and both a and b are constants of regression. Table 9 lists the constants of regression and the Pearson's R correlation coefficient for each projectile. The ballistic tables corresponding to the acceptance curves can be found in MIL-DTL-32341A (MR).[1]

Table 9 Constants of regression for the acceptance curves for AA2060

Projectile type	6055		
	a	b	R
0.30-cal. APM2 at 30°	–0.902	7.17	0.977
0.30-cal. APM2 at 0°	–1.33	6.40	0.998
0.50-cal. APM2 at 0°	–1.06	3.60	0.997
0.50-cal. FSP at 0°	–0.711	1.96	0.869
20-mm FSP at 0°	–1.07	1.43	0.996

5. Conclusions

A ballistic evaluation has been performed on AA2060 in the T8 temper. This report has compared the performance of AA2060 against existing military-specification Al-armor material, namely AA2195 and AA2139. AA2060 performed better than AA2195 and AA2139 against the 0.30-cal. APM2 and demonstrated similar performance against the 0.50-cal. APM2. For FSP projectiles, AA2060 had similar performance to AA2195 and AA2139 against the 0.50-cal. FSP but exhibited some scattered data. For the 20-mm FSP, AA2060 had performance lower than that of AA2195 and AA2139, with a greater performance gap at lower thickness than with higher ones. This report has also documented the calculations used to derive the acceptance tables included in the updated military specification MIL-DTL -32341A (MR).

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Appendix A. Ballistic Test Data: Individual Shot Results

This appendix appears in its original form, without editorial change.

0.30-cal APM2

Target:	**AA2060**	Date:	**8/20/2013**
Plate Number:	**215-014**	Location:	**EF 106**
Thickness, in:	**0.629**		
Thickness, mm:	**15.98**		
Hardness, BHN:	**159**		
Obliquity:	**30°**		
Projectile:	**0.30-cal AMP2**		
Velocity Measurement:	**Chrono**		

V_{50}:	**1921 ft/s**	Number of Shots:	**4**
Std Dev:	**19 ft/s**	Spread:	**44 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
1984	605	--	--	CP	No	12960	
1873	571	--	--	PP	No	12961	
1926	**587**	**--**	**--**	**CP**	**Yes**	**12962**	
1880	573	--	--	PP	No	12963	
1910	**582**	**--**	**--**	**PP**	**Yes**	**12964**	
1978	603	--	--	CP	No	12965	
1946	**593**	**--**	**--**	**CP**	**Yes**	**12966**	
1902	**580**	**--**	**--**	**PP**	**Yes**	**12967**	

Target:	**AA2060**	Date:	**8/19/2013**
Plate Number:	**215-016**	Location:	**EF 106**
Thickness, in:	**0.678**		
Thickness, mm:	**17.22**		
Hardness, BHN:	**166**		
Obliquity:	**30°**		
Projectile:	**0.30-cal AMP2**		
Velocity Measurement:	**Chrono**		

V_{50}:	**2059 ft/s**	Number of Shots:	**4**
Std Dev:	**19 ft/s**	Spread:	**43 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
1939	591	--	--	PP	No	12954	
2033	**620**	**--**	**--**	**PP**	**Yes**	**12955**	
2158	658	--	--	CP	No	12956	
2076	**633**	**--**	**--**	**CP**	**Yes**	**12957**	
2055	**626**	**--**	**--**	**PP**	**Yes**	**12958**	
2070	**631**	**--**	**--**	**CP**	**Yes**	**12959**	

Target:	**AA2060**	Date:	**8/15/2013**
Plate Number:	**425-801**	Location:	**EF 106**
Thickness, in:	**0.851**		
Thickness, mm:	**21.62**		
Hardness, BHN:	**159**		
Obliquity:	**30°**		
Projectile:	**0.30-cal AMP2**		
Velocity Measurement:	**Chrono**		

V_{50}:	**2319 ft/s**	Number of Shots:	**4**
Std Dev:	**14 ft/s**	Spread:	**33 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2323	**708**	**--**	**--**	**CP**	**Yes**	**12946**	
2211	674	--	--	PP	No	12947	
2269	692	--	--	PP	No	12948	
2250	686	--	--	PP	No	12949	
2303	**702**	**--**	**--**	**PP**	**Yes**	**12950**	
2314	**705**	**--**	**--**	**PP**	**Yes**	**12951**	
2369	722	--	--	CP	No	12952	
2336	**712**	**--**	**--**	**CP**	**Yes**	**12953**	

Target:	**AA2060**	Date:	**8/14/2013**
Plate Number:	**425-801**	Location:	**EF 106**
Thickness, in:	**0.851**		
Thickness, mm:	**21.62**		
Hardness, BHN:	**159**		
Obliquity:	**0°**		
Projectile:	**0.30-cal AMP2**		
Velocity Measurement:	**Chrono**		

V_{50}:	**2107 ft/s**	Number of Shots:	**4**
Std Dev:	**22 ft/s**	Spread:	**48 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2095	**639**	**--**	**--**	**PP**	**Yes**	**12940**	
2188	667	--	--	CP	No	12941	
2068	630	--	--	PP	No	12942	
2120	**646**	**--**	**--**	**CP**	**Yes**	**12943**	
2083	**635**	**--**	**--**	**PP**	**Yes**	**12944**	
2131	**649**	**--**	**--**	**CP**	**Yes**	**12945**	

Target:	**AA2060**	Date:	**8/13/2013**
Plate Number:	**215-019**	Location:	**EF 106**
Thickness, in:	**0.901**		
Thickness, mm:	**22.89**		
Hardness, BHN:	**156**		
Obliquity:	**0°**		
Projectile:	**0.30-cal AMP2**		
Velocity Measurement:	**Chrono**		

V_{50}:	**2161 ft/s**	Number of Shots:	**4**
Std Dev:	**30 ft/s**	Spread:	**57 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2188	**667**	**--**	**--**	**CP**	**Yes**	**12935**	
2111	643	--	--	PP	No	12936	
2186	**666**	**--**	**--**	**CP**	**Yes**	**12937**	
2140	**652**	**--**	**--**	**PP**	**Yes**	**12938**	
2131	**649**	**--**	**--**	**PP**	**Yes**	**12939**	

Target:	**AA2060**	Date:	**8/8/2013**
Plate Number:	**425-871**	Location:	**EF 106**
Thickness, in:	**0.898**		
Thickness, mm:	**22.81**		
Hardness, BHN:	**156**		
Obliquity:	**0°**		
Projectile:	**0.30-cal AMP2**		
Velocity Measurement:	**Chrono**		

V_{50}:	**2189 ft/s**	Number of Shots:	**4**
Std Dev:	**26 ft/s**	Spread:	**57 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2262	689	--	--	CP	No	12928	
2242	683	--	--	CP	No	12929	
2107	642	--	--	PP	No	12930	
2174	**663**	**--**	**--**	**PP**	**Yes**	**12931**	
2225	**678**	**--**	**--**	**CP**	**Yes**	**12932**	
2187	**667**	**--**	**--**	**CP**	**Yes**	**12933**	
2168	**661**	**--**	**--**	**PP**	**Yes**	**12934**	

Target:	**AA2060**	Date:	**8/7/2013**
Plate Number:	**425-841**	Location:	**EF 106**
Thickness, in:	**0.960**		
Thickness, mm:	**24.38**		
Hardness, BHN:	**159**		
Obliquity:	**0°**		
Projectile:	**0.30-cal AMP2**		
Velocity Measurement:	**Chrono**		

V_{50}:	**2243 ft/s**	Number of Shots:	**4**
Std Dev:	**29 ft/s**	Spread:	**60 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2135	651	--	--	PP	No	12920	
2313	705	--	--	CP	No	12921	
2188	667	--	--	PP	No	12922	
2228	**679**	**--**	**--**	**PP**	**Yes**	**12923**	
2269	**692**	**--**	**--**	**CP**	**Yes**	**12924**	
2209	**673**	**--**	**--**	**PP**	**Yes**	**12925**	
2295	699	--	--	CP	No	12926	
2265	**690**	**--**	**--**	**CP**	**Yes**	**12927**	

Target:	**AA2060**	Date:	**8/26/2013**
Plate Number:	**425-811**	Location:	**EF 106**
Thickness, in:	**1.188**		
Thickness, mm:	**30.18**		
Hardness, BHN:	**159**		
Obliquity:	**0°**		
Projectile:	**0.30-cal AMP2**		
Velocity Measurement:	**Chrono**		

V_{50}:	**2556 ft/s**	Number of Shots:	**6**
Std Dev:	**36 ft/s**	Spread:	**88 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2563	**781**	**--**	**--**	**PP**	**Yes**	**12984**	
2603	793	--	--	CP	No	12985	
2582	**787**	**--**	**--**	**CP**	**Yes**	**12986**	
2520	**768**	**--**	**--**	**PP**	**Yes**	**12987**	
2575	**785**	**--**	**--**	**CP**	**Yes**	**12988**	
2504	**763**	**--**	**--**	**PP**	**Yes**	**12989**	
2592	**790**	**--**	**--**	**CP**	**Yes**	**12990**	

Target:	**AA2060**	Date:	**8/21/2013**
Plate Number:	**425-822**	Location:	**EF 106**
Thickness, in:	**1.454**		
Thickness, mm:	**36.93**		
Hardness, BHN:	**166**		
Obliquity:	**0°**		
Projectile:	**0.30-cal AMP2**		
Velocity Measurement:	**Chrono**		

V_{50}:	**2916 ft/s**	Number of Shots:	**4**
Std Dev:	**19 ft/s**	Spread:	**37 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2870	875	--	--	PP	No	12968	
2901	**884**	**--**	**--**	**PP**	**Yes**	**12969**	
2992	912	--	--	CP	No	12970	
2970	905	--	--	CP	No	12971	
2936	**895**	**--**	**--**	**CP**	**Yes**	**12972**	
2927	**892**	**--**	**--**	**CP**	**Yes**	**12973**	
2899	**884**	**--**	**--**	**PP**	**Yes**	**12974**	

Target:	**AA2060**	Date:	**8/22/2013**
Plate Number:	**425-852**	Location:	**EF 106**
Thickness, in:	**1.441**		
Thickness, mm:	**36.60**		
Hardness, BHN:	**169**		
Obliquity:	**0°**		
Projectile:	**0.30-cal AMP2**		
Velocity Measurement:	**Chrono**		

V_{50}:	**2884 ft/s**	Number of Shots:	**4**
Std Dev:	**28 ft/s**	Spread:	**58 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2910	**887**	**--**	**--**	**CP**	**Yes**	**12975**	
2868	**874**	**--**	**--**	**PP**	**Yes**	**12976**	
2904	**885**	**--**	**--**	**CP**	**Yes**	**12977**	
2852	**869**	**--**	**--**	**PP**	**Yes**	**12978**	

Target:	**AA2060**	Date:	**8/23/2013**
Plate Number:	**215-012**	Location:	**EF 106**
Thickness, in:	**1.500**		
Thickness, mm:	**38.10**		
Hardness, BHN:	**159**		
Obliquity:	**0°**		
Projectile:	**0.30-cal AMP2**		
Velocity Measurement:	**Chrono**		

V_{50}:	**2945 ft/s**	Number of Shots:	**4**
Std Dev:	**26 ft/s**	Spread:	**58 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2974	**906**	**--**	**--**	**CP**	**Yes**	**12979**	
2884	879	--	--	PP	No	12980	
2916	**889**	**--**	**--**	**PP**	**Yes**	**12981**	
2931	**893**	**--**	**--**	**PP**	**Yes**	**12982**	
2958	**902**	**--**	**--**	**CP**	**Yes**	**12983**	

Target:	**AA2060**	Date:	**8/6/2013**
Plate Number:	**215-006**	Location:	**EF 106**
Thickness, in:	**1.518**		
Thickness, mm:	**38.56**		
Hardness, BHN:	**170**		
Obliquity:	**0°**		
Projectile:	**0.30-cal AMP2**		
Velocity Measurement:	**Chrono**		

V_{50}:	**2972 ft/s**		Number of Shots:	**4**
Std Dev:	**24 ft/s**		Spread:	**47 ft/s**
ZMR:	**N/A**			

Striking Velocity		Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
(ft/s)	(m/s)						
2863	873	--	--	PP	No	12914	
2922	891	--	--	PP	No	12915	
2998	**914**	**--**	**--**	**CP**	**Yes**	**12916**	
2952	**900**	**--**	**--**	**PP**	**Yes**	**12917**	
2986	**910**	**--**	**--**	**CP**	**Yes**	**12918**	
2951	**899**	**--**	**--**	**PP**	**Yes**	**12919**	

0.50-cal APM2

Target:	**AA2060**	Date:	**8/29/2013**
Plate Number:	**425-822**	Location:	**EF 108**
Thickness, in:	**1.454**		
Thickness, mm:	**36.93**		
Hardness, BHN:	**166**		
Obliquity:	**0°**		
Projectile:	**0.50-cal AMP2**		
Velocity Measurement:	**X-ray**		

V_{50}:	**2132 ft/s**	Number of Shots:	**6**
Std Dev:	**32 ft/s**	Spread:	**85 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2103	**641**	**--**	**--**	**PP**	**Yes**	**11551**	
2108	**642**	**--**	**--**	**PP**	**Yes**	**11552**	
2188	**667**	**--**	**--**	**CP**	**Yes**	**11553**	
2131	**649**	**--**	**--**	**CP**	**Yes**	**11554**	
2115	**645**	**--**	**--**	**PP**	**Yes**	**11555**	
2144	**653**	**--**	**--**	**CP**	**Yes**	**11556**	

Target:	**AA2060**	Date:	**8/28/2013**
Plate Number:	**425-852**	Location:	**EF 108**
Thickness, in:	**1.441**		
Thickness, mm:	**36.60**		
Hardness, BHN:	**163**		
Obliquity:	**0°**		
Projectile:	**0.50-cal AMP2**		
Velocity Measurement:	**X-ray**		

V_{50}:	**2127 ft/s**	Number of Shots:	**4**
Std Dev:	**17 ft/s**	Spread:	**38 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2079	634	--	--	PP	No	11545	
2144	**653**	**--**	**--**	**CP**	**Yes**	**11546**	
2088	636	--	--	PP	No	11547	
2106	**642**	**--**	**--**	**PP**	**Yes**	**11548**	
2122	**647**	**--**	**--**	**PP**	**Yes**	**11549**	
2135	**651**	**--**	**--**	**CP**	**Yes**	**11550**	

Target:	**AA2060**	Date:	**8/27/2013**
Plate Number:	**215-012**	Location:	**EF 108**
Thickness, in:	**1.500**		
Thickness, mm:	**38.10**		
Hardness, BHN:	**159**		
Obliquity:	**0°**		
Projectile:	**0.50-cal AMP2**		
Velocity Measurement:	**X-ray**		

V_{50}:	**2140 ft/s**	Number of Shots:	**4**
Std Dev:	**18 ft/s**	Spread:	**43 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2166	**660**	**--**	**--**	**CP**	**Yes**	**11539**	
2072	632	--	--	PP	No	11540	
2102	641	--	--	PP	No	11541	
2136	**651**	**--**	**--**	**CP**	**Yes**	**11542**	
2123	**647**	**--**	**--**	**PP**	**Yes**	**11543**	
2135	**651**	**--**	**--**	**PP**	**Yes**	**11544**	

Target:	**AA2060**	Date:	**8/26/2013**
Plate Number:	**215-006**	Location:	**EF 108**
Thickness, in:	**1.518**		
Thickness, mm:	**38.56**		
Hardness, BHN:	**170**		
Obliquity:	**0°**		
Projectile:	**0.50-cal AMP2**		
Velocity Measurement:	**X-ray**		

V_{50}:	**2164 ft/s**	Number of Shots:	**4**
Std Dev:	**28 ft/s**	Spread:	**59 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2184	**666**	**--**	**--**	**CP**	**Yes**	**11534**	
2078	633	--	--	PP	No	11535	
2125	**648**	**--**	**--**	**PP**	**Yes**	**11536**	
2164	**660**	**--**	**--**	**PP**	**Yes**	**11537**	
2184	**666**	**--**	**--**	**CP**	**Yes**	**11538**	

Target:	**AA2060**	Date:	**9/11/2013**
Plate Number:	**425-821**	Location:	**EF 108**
Thickness, in:	**1.955**		
Thickness, mm:	**49.66**		
Hardness, BHN:	**166**		
Obliquity:	**0°**		
Projectile:	**0.50-cal AMP2**		
Velocity Measurement:	**X-ray**		

V_{50}:	**2532 ft/s**	Number of Shots:	**4**
Std Dev:	**21 ft/s**	Spread:	**45 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2509	**765**	**--**	**--**	**PP**	**Yes**	**11586**	
2544	**775**	**--**	**--**	**CP**	**Yes**	**11587**	
2521	**768**	**--**	**--**	**PP**	**Yes**	**11588**	
2554	**778**	**--**	**--**	**CP**	**Yes**	**11589**	

Target:	**AA2060**	Date:	**9/10/2013**
Plate Number:	**425-851**	Location:	**EF 108**
Thickness, in:	**1.949**		
Thickness, mm:	**49.50**		
Hardness, BHN:	**163**		
Obliquity:	**0°**		
Projectile:	**0.50-cal AMP2**		
Velocity Measurement:	**X-ray**		

V_{50}:	**2509 ft/s**	Number of Shots:	**4**
Std Dev:	**24 ft/s**	Spread:	**51 ft/s**
ZMR:	**2 ft/s**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2498	**761**	**--**	**--**	**CP**	**Yes**	**11581**	
2450	747	--	--	PP	No	11582	
2493	**760**	**--**	**--**	**PP**	**Yes**	**11583**	
2544	**775**	**--**	**--**	**CP**	**Yes**	**11584**	
2500	**762**	**--**	**--**	**PP**	**Yes**	**11585**	

Target:	**AA2060**	Date:	**9/10/2013**
Plate Number:	**425-881**	Location:	**EF 108**
Thickness, in:	**1.956**		
Thickness, mm:	**49.68**		
Hardness, BHN:	**170**		
Obliquity:	**0°**		
Projectile:	**0.50-cal AMP2**		
Velocity Measurement:	**X-ray**		

V_{50}:	**2517 ft/s**	Number of Shots:	**4**
Std Dev:	**32 ft/s**	Spread:	**57 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2544	**775**	**--**	**--**	**CP**	**Yes**	**11576**	
2425	739	--	--	PP	No	11577	
2487	**758**	**--**	**--**	**PP**	**Yes**	**11578**	
2492	**760**	**--**	**--**	**PP**	**Yes**	**11579**	
2544	**775**	**--**	**--**	**CP**	**Yes**	**11580**	

Target:	**AA2060**	Date:	**9/9/2013**
Plate Number:	**215-011**	Location:	**EF 108**
Thickness, in:	**2.165**		
Thickness, mm:	**54.99**		
Hardness, BHN:	**166**		
Obliquity:	**0°**		
Projectile:	**0.50-cal AMP2**		
Velocity Measurement:	**X-ray**		

V_{50}:	**2646 ft/s**	Number of Shots:	**4**
Std Dev:	**19 ft/s**	Spread:	**40 ft/s**
ZMR:	**3 ft/s**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2675	**815**	**--**	**--**	**CP**	**Yes**	**11572**	
2635	**803**	**--**	**--**	**PP**	**Yes**	**11573**	
2636	**803**	**--**	**--**	**CP**	**Yes**	**11574**	
2639	**804**	**--**	**--**	**PP**	**Yes**	**11575**	

Target:	**AA2060**	Date:	**9/5/2013**
Plate Number:	**425-831**	Location:	**EF 108**
Thickness, in:	**2.444**		
Thickness, mm:	**62.08**		
Hardness, BHN:	**166**		
Obliquity:	**0°**		
Projectile:	**0.50-cal AMP2**		
Velocity Measurement:	**X-ray**		

V_{50}:	**2864 ft/s**		Number of Shots:	**4**
Std Dev:	**13 ft/s**		Spread:	**33 ft/s**
ZMR:	**1 ft/s**			

Striking Velocity		Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
(ft/s)	(m/s)						
2847	**868**	**--**	**--**	**PP**	**Yes**	**11567**	
2909	887	--	--	CP	No	11568	
2880	**878**	**--**	**--**	**CP**	**Yes**	**11569**	
2865	**873**	**--**	**--**	**PP**	**Yes**	**11570**	
2864	**873**	**--**	**--**	**CP**	**Yes**	**11571**	

Target:	**AA2060**	Date:	**8/30/2013**
Plate Number:	**425-861**	Location:	**EF 108**
Thickness, in:	**2.431**		
Thickness, mm:	**61.75**		
Hardness, BHN:	**166**		
Obliquity:	**0°**		
Projectile:	**0.50-cal AMP2**		
Velocity Measurement:	**X-ray**		

V_{50}:	**2847 ft/s**	Number of Shots:	**6**
Std Dev:	**36 ft/s**	Spread:	**85 ft/s**
ZMR:	**35 ft/s**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2689	820	--	--	PP	No	11557	
2878	**877**	**--**	**--**	**PP**	**Yes**	**11558**	
2966	904	--	--	CP	No	11559	
2918	889	--	--	CP	No	11560	
2921	890	--	--	CP	No	11561	
2882	**878**	**--**	**--**	**CP**	**Yes**	**11562**	
2843	**867**	**--**	**--**	**CP**	**Yes**	**11563**	
2797	**852**	**--**	**--**	**PP**	**Yes**	**11564**	
2811	**857**	**--**	**--**	**PP**	**Yes**	**11565**	
2872	**875**	**--**	**--**	**CP**	**Yes**	**11566**	

0.50-cal FSP

Target:	**AA2060**	Date:	**9/19/2013**
Plate Number:	**425-801**	Location:	**EF 108**
Thickness, in:	**0.851**		
Thickness, mm:	**21.62**		
Hardness, BHN:	**159**		
Obliquity:	**0°**		
Projectile:	**0.50-cal FSP**		
Velocity Measurement:	**Chrono**		

V_{50}:	**2514 ft/s**	Number of Shots:	**4**
Std Dev:	**23 ft/s**	Spread:	**50 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2712	827	--	--	CP	No	11619	
2519	**768**	**--**	**--**	**CP**	**Yes**	**11620**	
2346	715	--	--	PP	No	11621	
2459	749	--	--	PP	No	11622	
2494	**760**	**--**	**--**	**PP**	**Yes**	**11623**	
2499	**762**	**--**	**--**	**PP**	**Yes**	**11624**	
2544	**775**	**--**	**--**	**CP**	**Yes**	**11625**	

Target:	**AA2060**	Date:	**9/18/2013**
Plate Number:	**215-019**	Location:	**EF 108**
Thickness, in:	**0.901**		
Thickness, mm:	**22.89**		
Hardness, BHN:	**156**		
Obliquity:	**0°**		
Projectile:	**0.50-cal FSP**		
Velocity Measurement:	**Chrono**		

V_{50}:	**2998 ft/s**	Number of Shots:	**4**
Std Dev:	**19 ft/s**	Spread:	**41 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2991	**912**	**--**	**--**	**CP**	**Yes**	**11612**	
2924	891	--	--	PP	No	11613	
2985	**910**	**--**	**--**	**PP**	**Yes**	**11614**	
3026	**922**	**--**	**--**	**CP**	**Yes**	**11615**	
3033	924	--	--	CP	No	11616	
2929	893	--	--	PP	No	11617	
2988	**911**	**--**	**--**	**PP**	**Yes**	**11618**	

Target:	**AA2060**	Date:	**9/17/2013**
Plate Number:	**425-871**	Location:	**EF 108**
Thickness, in:	**0.898**		
Thickness, mm:	**22.81**		
Hardness, BHN:	**156**		
Obliquity:	**0°**		
Projectile:	**0.50-cal FSP**		
Velocity Measurement:	**Chrono**		

V_{50}:	**2962 ft/s**	Number of Shots:	**4**
Std Dev:	**21 ft/s**	Spread:	**49 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2814	858	--	--	PP	No	11603	
2834	864	--	--	PP	No	11604	
2931	893	--	--	PP	No	11605	
3044	928	--	--	CP	No	11606	
2968	**905**	**--**	**--**	**CP**	**Yes**	**11607**	
2934	**894**	**--**	**--**	**PP**	**Yes**	**11608**	
2964	**903**	**--**	**--**	**PP**	**Yes**	**11609**	
3025	922	--	--	CP	No	11610	
2983	**909**	**--**	**--**	**CP**	**Yes**	**11611**	

Target:	**AA2060**	Date:	**9/16/2013**
Plate Number:	**425-841**	Location:	**EF 108**
Thickness, in:	**0.960**		
Thickness, mm:	**24.38**		
Hardness, BHN:	**159**		
Obliquity:	**0°**		
Projectile:	**0.50-cal FSP**		
Velocity Measurement:	**Chrono**		

V_{50}:	**3239 ft/s**	Number of Shots:	**6**
Std Dev:	**35 ft/s**	Spread:	**87 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
3282	**1000**	**--**	**--**	**CP**	**Yes**	**11596**	
3144	958	--	--	PP	No	11597	
3262	**994**	**--**	**--**	**CP**	**Yes**	**11598**	
3195	**974**	**--**	**--**	**PP**	**Yes**	**11599**	
3213	**979**	**--**	**--**	**PP**	**Yes**	**11600**	
3218	**981**	**--**	**--**	**PP**	**Yes**	**11601**	
3265	**995**	**--**	**--**	**CP**	**Yes**	**11602**	

20-mm FSP

Target:	**AA2060**	Date:	**9/26/2013**
Plate Number:	**215-019**	Location:	**EF 110G**
Thickness, in:	**0.903**		
Thickness, mm:	**22.94**		
Hardness, BHN:	**159**		
Obliquity:	**0°**		
Projectile:	**20-mm FSP**		
Velocity Measurement:	**X-ray**		

V_{50}:	**1401 ft/s**	Number of Shots:	**10**
Std Dev:	**56 ft/s**	Spread:	**151 ft/s**
ZMR:	**79 ft/s**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
1462	**446**	**--**	**--**	**PP**	**Yes**	**14557**	
1485	453	--	--	CP	No	14558	
1449	**442**	**--**	**--**	**CP**	**Yes**	**14559**	
1479	**451**	**--**	**--**	**CP**	**Yes**	**14560**	
1453	**443**	**--**	**--**	**CP**	**Yes**	**14561**	
1383	**422**	**--**	**--**	**CP**	**Yes**	**14562**	
1304	397	--	--	PP	No	14563	
1328	**405**	**--**	**--**	**PP**	**Yes**	**14564**	
1341	**409**	**--**	**--**	**PP**	**Yes**	**14565**	
1346	**410**	**--**	**--**	**PP**	**Yes**	**14566**	
1361	**415**	**--**	**--**	**PP**	**Yes**	**14567**	
1403	**415**	**--**	**--**	**CP**	**Yes**	**14568**	

Target:	**AA2060**	Date:	**9/27/2013**
Plate Number:	**425-871**	Location:	**EF 110G**
Thickness, in:	**0.904**		
Thickness, mm:	**22.96**		
Hardness, BHN:	**159**		
Obliquity:	**0°**		
Projectile:	**20-mm FSP**		
Velocity Measurement:	**X-ray**		

V_{50}:	**1298 ft/s**	Number of Shots:	**4**
Std Dev:	**16 ft/s**	Spread:	**34 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
1481	451	--	--	CP	No	14569	
1361	415	--	--	CP	No	14570	
1262	385	--	--	PP	No	14571	
1138	347	--	--	PP	No	14572	
1274	**388**	**--**	**--**	**PP**	**Yes**	**14573**	
1303	**397**	**--**	**--**	**PP**	**Yes**	**14574**	
1308	**399**	**--**	**--**	**CP**	**Yes**	**14575**	
1305	**398**	**--**	**--**	**CP**	**Yes**	**14576**	

Target:	**AA2060**	Date:	**9/30/2013**
Plate Number:	**425-841**	Location:	**EF 110G**
Thickness, in:	**0.953**		
Thickness, mm:	**24.21**		
Hardness, BHN:	**163**		
Obliquity:	**0°**		
Projectile:	**20-mm FSP**		
Velocity Measurement:	**X-ray**		

V_{50}:	**1468 ft/s**	Number of Shots:	**4**
Std Dev:	**17 ft/s**	Spread:	**38 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
1681	512	--	--	CP	No	14579	
1566	477	--	--	CP	No	14580	
1532	467	--	--	CP	No	14581	
1456	**444**	**--**	**--**	**PP**	**Yes**	**14582**	
1490	**454**	**--**	**--**	**CP**	**Yes**	**14583**	
1472	**449**	**--**	**--**	**CP**	**Yes**	**14584**	
1452	**443**	**--**	**--**	**PP**	**Yes**	**14585**	

Target:	**AA2060**	Date:	**10/1/2013**
Plate Number:	**425-811**	Location:	**EF 110G**
Thickness, in:	**1.183**		
Thickness, mm:	**30.05**		
Hardness, BHN:	**159**		
Obliquity:	**0°**		
Projectile:	**20-mm FSP**		
Velocity Measurement:	**X-ray**		

V_{50}:	**1965 ft/s**		Number of Shots:	**4**
Std Dev:	**19 ft/s**		Spread:	**44 ft/s**
ZMR:	**0 ft/s**			

Striking Velocity		Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
(ft/s)	(m/s)						
2026	617	--	--	CP	No	14586	
1937	**590**	**--**	**--**	**PP**	**Yes**	**14587**	
1971	**601**	**--**	**--**	**PP**	**Yes**	**14588**	
1971	**601**	**--**	**--**	**CP**	**Yes**	**14589**	
1981	**604**	**--**	**--**	**CP**	**Yes**	**14590**	

Target:	**AA2060**	Date:	**10/2/2013**
Plate Number:	**425-822**	Location:	**EF 110G**
Thickness, in:	**1.458**		
Thickness, mm:	**37.03**		
Hardness, BHN:	**156**		
Obliquity:	**0°**		
Projectile:	**20-mm FSP**		
Velocity Measurement:	**X-ray**		

V_{50}:	**2892 ft/s**	Number of Shots:	**4**
Std Dev:	**25 ft/s**	Spread:	**50 ft/s**
ZMR:	**0 ft/s**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2685	818	--	--	PP	No	14592	
2880	**878**	**--**	**--**	**PP**	**Yes**	**14593**	
2929	**893**	**--**	**--**	**CP**	**Yes**	**14594**	
2879	**877**	**--**	**--**	**CP**	**Yes**	**14595**	
2879	**877**	**--**	**--**	**PP**	**Yes**	**14596**	

Target:	**AA2060**	Date:	**10/3/2013**
Plate Number:	**425-852**	Location:	**EF 110G**
Thickness, in:	**1.441**		
Thickness, mm:	**36.60**		
Hardness, BHN:	**163**		
Obliquity:	**0°**		
Projectile:	**20-mm FSP**		
Velocity Measurement:	**X-ray**		

V_{50}:	**2839 ft/s**	Number of Shots:	**4**
Std Dev:	**17 ft/s**	Spread:	**35 ft/s**
ZMR:	**35 ft/s**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
2898	883	--	--	CP	No	14597	
2848	**868**	**--**	**--**	**CP**	**Yes**	**14598**	
2814	**858**	**--**	**--**	**CP**	**Yes**	**14599**	
2793	851	--	--	PP	No	14600	
2800	853	--	--	PP	No	14601	
2844	**867**	**--**	**--**	**PP**	**Yes**	**14602**	
2849	**868**	**--**	**--**	**PP**	**Yes**	**14603**	

Target:	**AA2060**	Date:	**10/8/2013**
Plate Number:	**215-012**	Location:	**EF 110G**
Thickness, in:	**1.500**		
Thickness, mm:	**38.10**		
Hardness, BHN:	**170**		
Obliquity:	**0°**		
Projectile:	**20-mm FSP**		
Velocity Measurement:	**X-ray**		

V_{50}:	**2983 ft/s**	Number of Shots:	**4**
Std Dev:	**22 ft/s**	Spread:	**54 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
3013	**918**	**--**	**--**	**CP**	**Yes**	**14608**	
2982	**909**	**--**	**--**	**CP**	**Yes**	**14609**	
2959	**902**	**--**	**--**	**PP**	**Yes**	**14610**	
2979	**908**	**--**	**--**	**PP**	**Yes**	**14611**	

Target:	**AA2060**	Date:	**10/9/2013**
Plate Number:	**215-006**	Location:	**EF 110G**
Thickness, in:	**1.513**		
Thickness, mm:	**38.43**		
Hardness, BHN:	**163**		
Obliquity:	**0°**		
Projectile:	**20-mm FSP**		
Velocity Measurement:	**X-ray**		

V_{50}:	**3027 ft/s**	Number of Shots:	**4**
Std Dev:	**3 ft/s**	Spread:	**8 ft/s**
ZMR:	**2 ft/s**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
3101	945	--	--	CP	No	14612	
3071	936	--	--	CP	No	14613	
2995	913	--	--	PP	No	14614	
2992	912	--	--	PP	No	14615	
3031	**924**	**--**	**--**	**CP**	**Yes**	**14616**	
3023	**921**	**--**	**--**	**PP**	**Yes**	**14617**	
2955	901	--	--	PP	No	14618	
3028	**923**	**--**	**--**	**PP**	**Yes**	**14619**	
3026	**922**	**--**	**--**	**CP**	**Yes**	**14620**	

Target:	**AA2060**	Date:	**10/6/2013**
Plate Number:	**425-821**	Location:	**EF 110G**
Thickness, in:	**1.950**		
Thickness, mm:	**49.53**		
Hardness, BHN:	**156**		
Obliquity:	**0°**		
Projectile:	**20-mm FSP**		
Velocity Measurement:	**X-ray**		

V_{50}:	**3979 ft/s**	Number of Shots:	**4**
Std Dev:	**21 ft/s**	Spread:	**49 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
3093	943	--	--	PP	No	14621	
3219	981	--	--	PP	No	14622	
3386	1032	--	--	PP	No	14623	
4771	1454	--	--	CP	No	14628	
4527	1380	--	--	CP	No	14629	
4425	1349	--	--	N/A	No	14630	FSP hit stripper plate - No test
4447	1355	--	--	CP	No	14631	
4346	1325	--	--	CP	No	14632	
4149	1265	--	--	CP	No	14633	
4063	1238	--	--	CP	No	14634	
3907	1191	--	--	PP	No	14635	
3954	**1205**	**--**	**--**	**PP**	**Yes**	**14636**	
4029	1228	--	--	CP	No	14637	
4003	**1220**	**--**	**--**	**CP**	**Yes**	**14638**	
3973	**1211**	**--**	**--**	**PP**	**Yes**	**14639**	
3987	**1215**	**--**	**--**	**CP**	**Yes**	**14640**	

Target:	**AA2060**	Date:	**10/23/2013**
Plate Number:	**425-851**	Location:	**EF 110G**
Thickness, in:	**1.950**		
Thickness, mm:	**49.53**		
Hardness, BHN:	**156**		
Obliquity:	**0°**		
Projectile:	**20-mm FSP**		
Velocity Measurement:	**X-ray**		

V_{50}:	**4047 ft/s**	Number of Shots:	**6**
Std Dev:	**25 ft/s**	Spread:	**70 ft/s**
ZMR:	**N/A**		

Striking Velocity (ft/s)	Striking Velocity (m/s)	Pitch (deg)	Yaw (deg)	Result (PP/CP)	Used for V_{50} (Yes/No)	Shot Number	Comments
3957	1206	0.75	-0.25	PP	No	14641	
4145	1263	0.00	-0.25	CP	No	14642	
4142	1262	0.25	-0.25	CP	No	14643	
4021	**1226**	**1.00**	**1.25**	**PP**	**Yes**	**14644**	
4091	1247	0.25	0.00	CP	No	14645	
4091	**1247**	**1.00**	**-0.75**	**PP**	**Yes**	**14646**	
4118	1255	0.00	-0.50	CP	No	14647	
4038	**1231**	**-0.25**	**0.00**	**CP**	**Yes**	**14648**	
4053	**1235**	**-0.25**	**1.25**	**CP**	**Yes**	**14649**	
4050	**1234**	**1.25**	**-0.25**	**CP**	**Yes**	**14650**	
4026	**1227**	**0.75**	**0.25**	**PP**	**Yes**	**14651**	

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Appendix B. Additional Ballistic Test Data

The following tables list data collected by Aberdeen Test Center.[1]

Table B-1 APM2 0.30-cal., 30° obliquity ballistic performance

Plate ID	Nominal thickness		Actual thickness		Areal density		Ballistic limit		Standard deviation	
	(mm)	(inches)	(mm)	(inches)	(kg/m^2)	(psf)	(m/s)	(fps)	(m/s)	(fps)
215-014	15.88	0.63	16.13	0.635	43.75	8.96	590	1,935	6	21
215-016	15.88	0.63	17.35	0.683	47.05	9.64	607	1,990	7	23

Table B-2 APM2 0.30-cal., 0° obliquity ballistic performance

Plate ID	Nominal thickness		Actual thickness		Areal density		Ballistic limit		Standard deviation	
	(mm)	(inches)	(mm)	(inches)	(kg/m^2)	(psf)	(m/s)	(fps)	(m/s)	(fps)
425-811	28.58	1.13	30.15	1.187	81.77	16.75	781	2,564	5	16
425-801	22.23	0.88	20.93	0.824	56.77	11.63	636	2,088	3	9
215-019	22.23	0.88	23.11	0.910	62.69	12.84	671	2,200	8	25
425-871	22.23	0.88	22.91	0.902	62.14	12.73	662	2,171	9	31
425-822	38.10	1.50	36.98	1.456	100.30	20.54	887	2,910	8	26

Table B-3 APM2 0.50-cal., 0° obliquity ballistic performance

Plate ID	Nominal thickness		Actual thickness		Areal density		Ballistic limit		Standard deviation	
	(mm)	(inches)	(mm)	(inches)	(kg/m^2)	(psf)	(m/s)	(fps)	(m/s)	(fps)
425-882	63.50	2.50	62.99	2.480	170.85	34.99	872	2,860	5	18
425-831	63.50	2.50	62.15	2.447	168.58	34.53	874	2,868	5	18
425-881	50.80	2.00	49.86	1.963	135.23	27.70	766	2,512	5	16
425-821	50.80	2.00	49.78	1.960	135.03	27.66	764	2,506	8	25
215-011	53.98	2.13	54.84	2.159	148.73	30.46	820	2,690	7	23
425-822	38.10	1.50	36.98	1.456	100.30	20.54	642	2,108	5	16

Table B-4 0.50-cal. FSP, 0° obliquity ballistic performance

Plate ID	Nominal thickness		Actual thickness		Areal density		Ballistic limit		Standard deviation	
	(mm)	(inches)	(mm)	(inches)	(kg/m^2)	(psf)	(m/s)	(fps)	(m/s)	(fps)
425-811	28.58	1.13	30.15	1.187	81.77	16.75	1,259	4,132	2	7
215-014	15.88	0.63	16.13	0.635	43.75	8.96	502	1,646	4	13
215-016	15.88	0.63	17.35	0.683	47.05	9.64	531	1,743	6	21
425-801	22.23	0.88	20.93	0.824	56.77	11.63	793	2,603	7	24
215-019	22.23	0.88	23.11	0.910	62.69	12.84	936	3,070	5	18
425-871	22.23	0.88	22.91	0.902	62.14	12.73	868	2,847	7	23

[1]MIL-DTL-32341 (MR). Armor plate, aluminum, alloy 2139 weldable and alloy 2195 and 2060 unweldable appliqué. Aberdeen Proving Ground (MD): Army Research Laboratory (US); 2015 Apr 15.

Table B-5 FSP 20-mm, 0° obliquity ballistic performance

Plate ID	Nominal thickness		Actual thickness		Areal density		Ballistic limit		Standard deviation	
	(mm)	(inches)	(mm)	(inches)	(kg/m^2)	(psf)	(m/s)	(fps)	(m/s)	(fps)
425-811	28.58	1.13	30.15	1.187	81.77	16.75	613	2,010	7	24
215-019	22.23	0.88	23.11	0.910	62.69	12.84	406	1,332	7	24
425-871	22.23	0.88	22.91	0.902	62.14	12.73	384	1,260	5	16
425-881	50.80	2.00	49.86	1.963	135.23	27.70	1237	4,058	8	26
425-821	50.80	2.00	49.78	1.960	135.03	27.66	1203	3,948	8	26
215-011	53.98	2.13	54.84	2.159	148.73	30.46	1356	4,450	9	29
425-822	38.10	1.50	36.98	1.456	100.30	20.54	848	2,781	8	27

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List of Symbols, Abbreviations, and Acronyms

AA	aluminum alloy
Al	aluminum
AP	armor-piercing
ARL	US Army Research Laboratory
ATC	Aberdeen Test Center
CP	complete penetration
DAC	Defense Acquisition Challenge
EF	experimental facility
FSP	fragment-simulating projectile
IR	infrared
OSD	US Office of the Secretary of Defense
PP	partial penetration

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